

A HELICAL ANTENNA AT K BAND

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A HELICAL ANTENNA AT K BAND

by

William S. Kremidas

Lieutenant, United States Navy

Submitted in partial fulfillment  
of the requirements  
for the degree of  
MASTER OF SCIENCE  
IN  
ENGINEERING ELECTRONICS

United States Naval Postgraduate School  
Monterey, California

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This work is accepted as fulfilling  
the thesis requirements for the degree of

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IN  
ENGINEERING ELECTRONICS

from the  
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## PREFACE

The work presented in this paper was done at the Bendix Aviation Corporation Research and Development Laboratories in Detroit, Michigan during the period from 3 January to 15 March 1955. It was done to fulfill a need of the company for a test receiving antenna having almost circular polarization. Specific requirements were set forth concerning bandwidth, beamwidth and axial ratio. The structure had to be small and capable of withstanding an acceleration of 500g. It was felt that a helical antenna might best meet these demands.

The author wishes to express his gratitude for the kind assistance and suggestions given him by I. Rudolph and J. Cheal of Bendix Aviation Corporation and by Professor J. Chaney of the U. S. Naval Postgraduate School. The author also wishes to acknowledge the cooperation of the American Institute of Physics for permission to reproduce Figures 3, 4, and 5 as well as of the McGraw-Hill Book Company, Inc. for permission to reproduce Figure 6.

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# TABLE OF SYMBOLS

A	-axial length of helix = $nS$
a	-radius of helical conductor
A.R.	-axial ratio of polarization ellipse
C	-circumference of helix = $\pi D$
c	-velocity of light
D	-diameter of helix (center to center)
d	-diameter of helical conductor
$E_L$	-left-hand circularly polarized wave
$E_R$	-right-hand circularly polarized wave
G	-ground plane diameter
g	-distance of helix proper from ground plane
k	- $\sqrt{\mu\epsilon}$
L	-helical length of one turn
n	-number of turns
p	-phase velocity factor = $v/c$
R	-radiation mode designation
S	-spacing between turns (center to center)
T	-transmission mode designation
v	-phase velocity of wave propagating along helical conductor
VSWR	-voltage standing wave ratio

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$\alpha$	-pitch angle of helix = $\arctan S/\pi D$
$\beta$	-beamwidth between half-power points
$\epsilon$	- dielectric constant of medium
$\lambda$	-wavelength, when used as a subscript signifies the dimension is measured in wavelengths
$\mu$	-permeability of medium
$\omega$	- $2\pi \times$ (frequency)

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# CHAPTER I

## INTRODUCTION

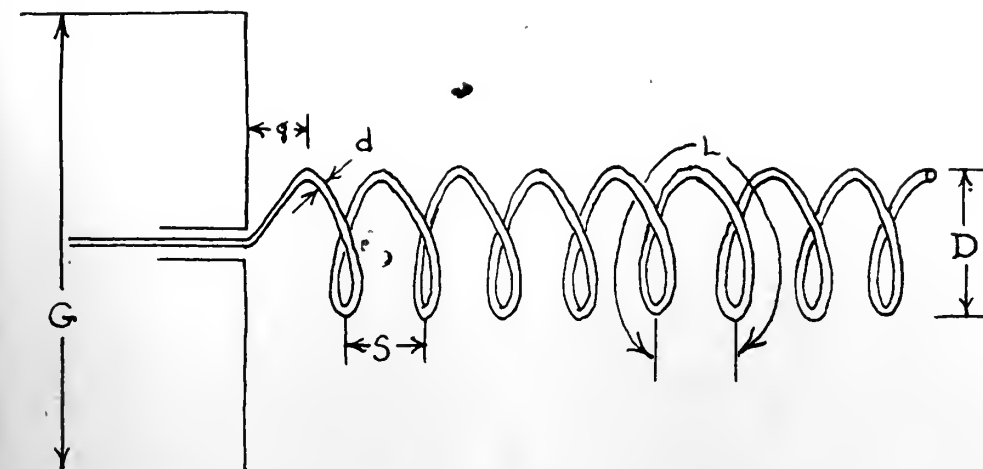
Within the past decade the helical antenna has been developed and employed in communications applications for the amateur and television bands of the frequency spectrum. The radiation pattern of a helix possesses elliptical polarization generally, but the antenna can be made to radiate circularly polarized waves by proper choice of dimensions. The antenna's physical configuration is relatively small and easy to construct, the dimensions not being too critical. The feed is simple, directivity good, and terminal impedance relatively constant over a reasonable wide bandwidth. Helical antennas have been constructed having a bandwidth ratio of 1.7 to 1.0 [10]. Matching problems are not too difficult generally. The foregoing properties make the helical antenna a very desirable one for many applications. The symbols used to describe the helix are given in Figures 1 and 2.

Because of these desirable characteristics of the helical antenna, particularly the broadband operation and circular polarization, it was believed that it might be gainfully employed at the microwave region of the spectrum. The purpose of this paper is to investigate this possibility and specifically to determine if a helix is a practical radiator at K

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- D - diameter of helix (center to center)
- d - diameter of helix conductor
- C - circumference of helix
- G - diameter of ground plane
- g - distance from ground plane to first turn of helix
- L - length of one turn
- n - number of turns
- S - spacing between turns (center to center)
- $\alpha$  - helix pitch angle

Figure 1. The Helical Antenna and Associated Dimensions

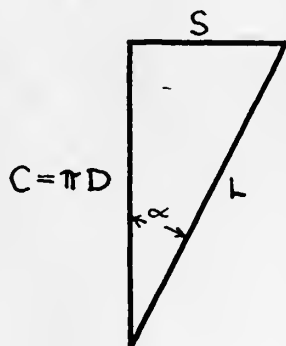


Figure 2. Relation between C, S, L, and  $\alpha$  of the Helix

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The first few chapters of the paper will be devoted to a general discussion of the helical antenna and its characteristics as well as a summary of design data available to date. The remaining chapters will deal with the particular problem of obtaining at K band a helical antenna whose general characteristics are not distorted from those at lower frequencies and the technique employed to obtain the results.



## CHAPTER II

### GENERAL PROPERTIES OF THE HELICAL ANTENNA

The helix is a familiar geometric form which has been used extensively in electrical circuits as an inductor. Another of its applications is in the traveling-wave tube where it is employed because of its inherent ability to delay the propagation of an electromagnetic wave. More recently it has been applied to the antenna field.

In considering the helix as an antenna, it is advantageous to regard it as a basic type of which the loop and straight-wire antennas are special cases, rather than as a unique form of its own. Thus, a helix collapses to a loop, as the pitch angle of the helix becomes zero. Similarly, as the pitch angle is increased to ninety degrees, the antenna becomes a linear conductor.

On the helix, transmission and radiation modes exist and are used to describe particular propagations. The transmission mode defines electromagnetic wave propagation along an infinite helix which constitutes an infinite transmission line or waveguide. The radiation mode is employed to describe the far field pattern of a finite helix.

For a helix of given dimensions, several transmission modes are possible depending on the frequency. At the lowest

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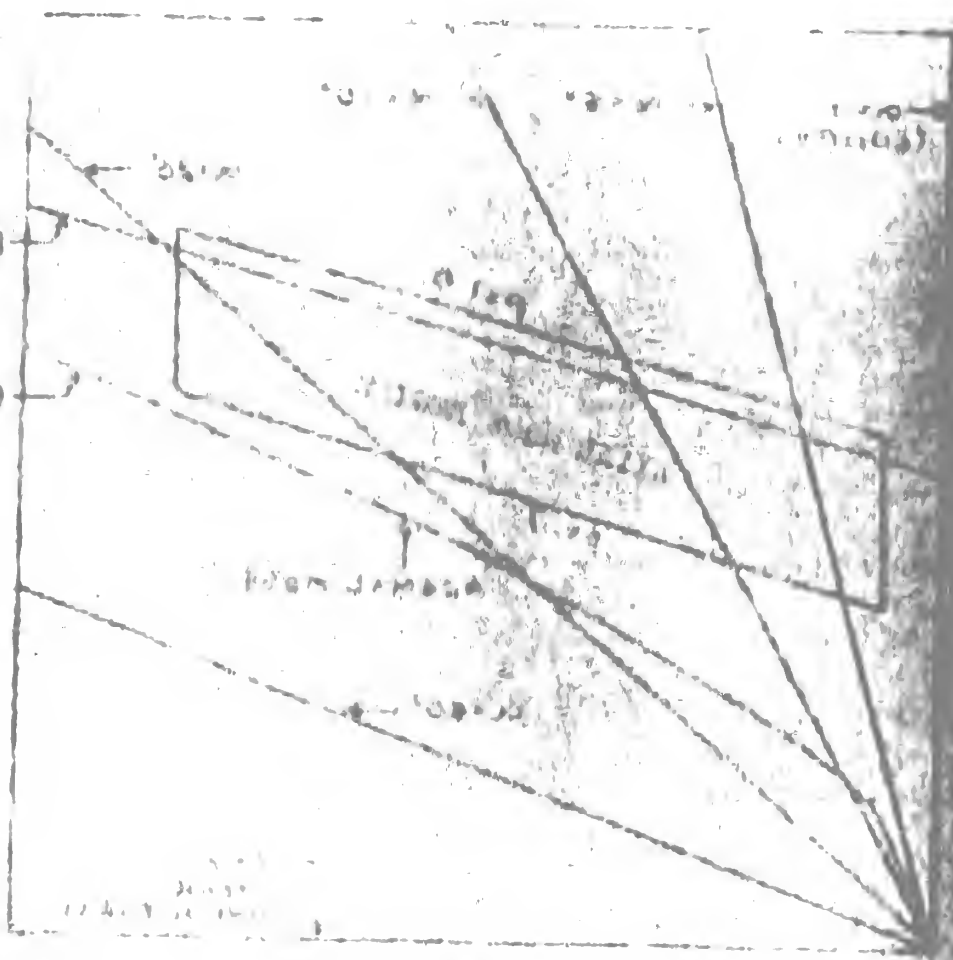
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frequency the lowest transmission mode, designated as  $T_0$ , occurs. This mode has adjacent regions of positive and negative charge separated by many turns and is the important mode for traveling-wave tubes. An appreciable axial component of electric field is present in this mode, and this interacts with the electron stream of the traveling-wave tube. It is possible for a helix excited in the  $T_0$  transmission mode to radiate. When this occurs, the normal radiation mode,  $T_0R_0$ , results. In the normal mode the radiation field is a maximum in a direction perpendicular to the helix axis and is almost circularly polarized over a limited frequency range. At other frequencies the polarization varies from elliptical to linear. This mode has been described mathematically by Wheeler [16]. Figure 3 [12] shows the curve on which the polarization ellipse becomes a circle. This condition is obtained when

$$D = (2S)^{1/2}/\pi .$$

The dimensions of the helix must be small compared to the wavelength, and therefore this mode is not desirable for this investigation due to the extreme small size involved.

As the frequency is increased to the point where the circumference of the helix is on the order of one wavelength, the  $T_1$  transmission mode occurs. For small pitch angles, the helix has adjacent regions of positive and negative charge separated by about one-half turn. Thus at a given instant,





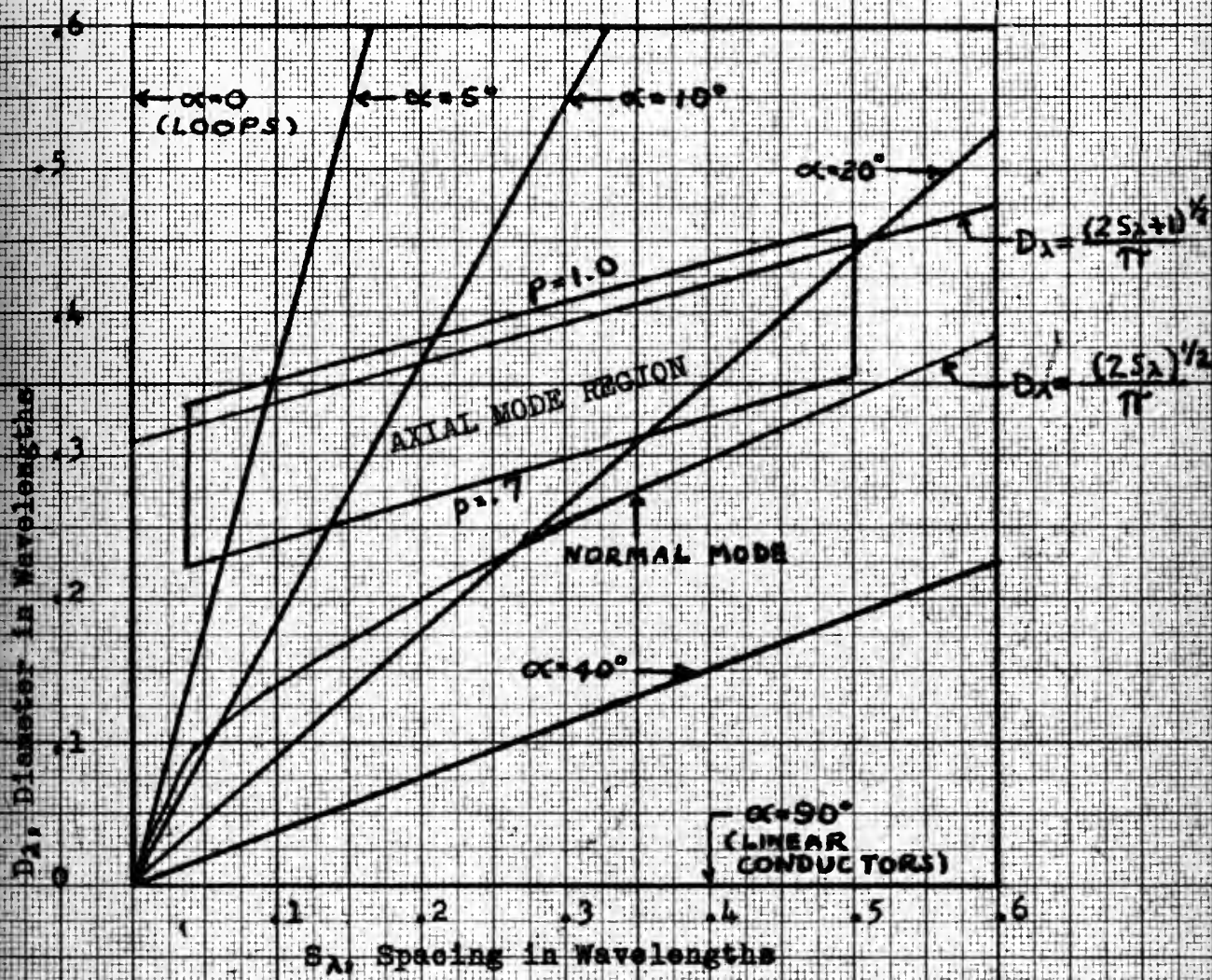


Figure 3. Diameter-spacing Chart for the Helix Showing the Dimensions for Various Radiation Modes (Courtesy of the American Institute of Physics)

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adjacent current elements are in phase and so contribute to give a finite field at a distance. This is the  $T_1R_1$  mode, commonly called the axial, or beam, mode of radiation and occurs when the helix circumference is about one wavelength. The axial mode has its maximum radiation field along the helix axis, and it can be made almost circularly polarized over a relatively wide bandwidth by proper choice of dimensions. This mode is also shown in Figure 3, and is defined approximately near its upper limit by the curve

$$D = (2S + 1)^{1/2} / \pi.$$

It is bounded by a region in which the relative phase velocity,  $p$ , varies from 0.7 to 1.0 as is indicated on the curve. It is this mode which is of particular interest to this investigation.

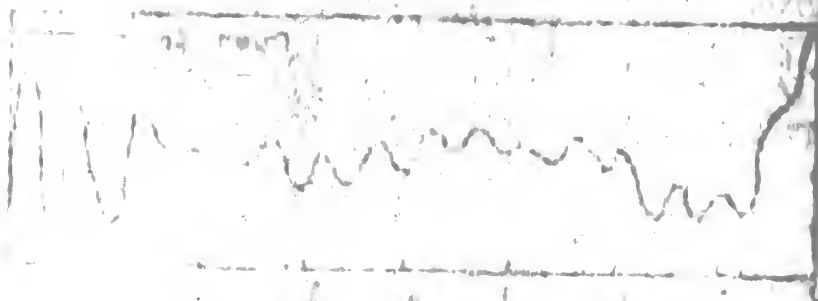
In discussing the properties of the helical antenna, one must consider the current distribution along the helix. Measured current distributions for the normal and axial modes of radiation are given in Figure 4. When the circumference of the helix is less than about two-thirds wavelengths, the current distribution is nearly sinusoidal as on a long, straight antenna and produces the normal radiation mode. However, when the circumference is on the order of one wavelength, the measured current distribution is relatively uniform over the middle portion of the helix. By assuming there are two outward traveling waves of different phase velocities, one (1)



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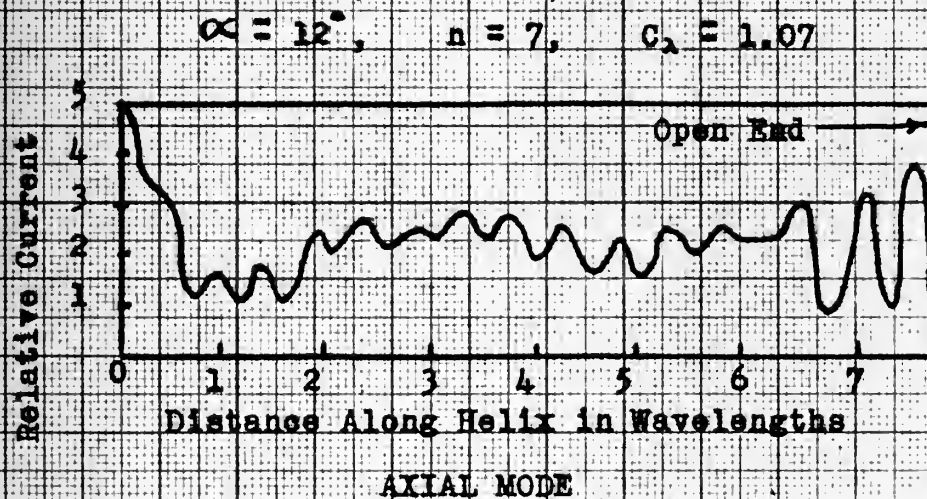
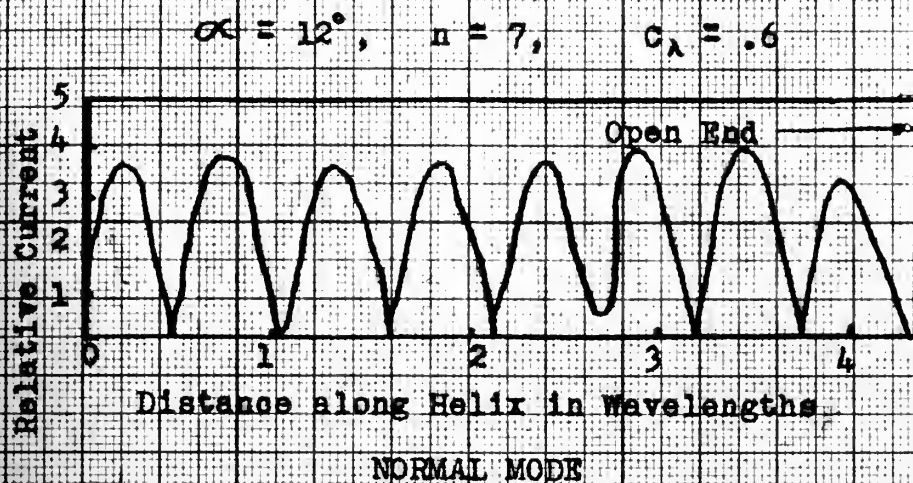


Figure 4. Measured Current Distributions on Helices  
(Courtesy of the American Institute of Physics)



attenuated and the other (2) constant, and two smaller returning traveling waves (3 and 4), as shown in Figure 5, J.A.

Marsh [I3] has been able to account for the axial mode current distribution shown in Figure 4. This type of distribution is generally characteristic of a helix radiating in the axial mode.

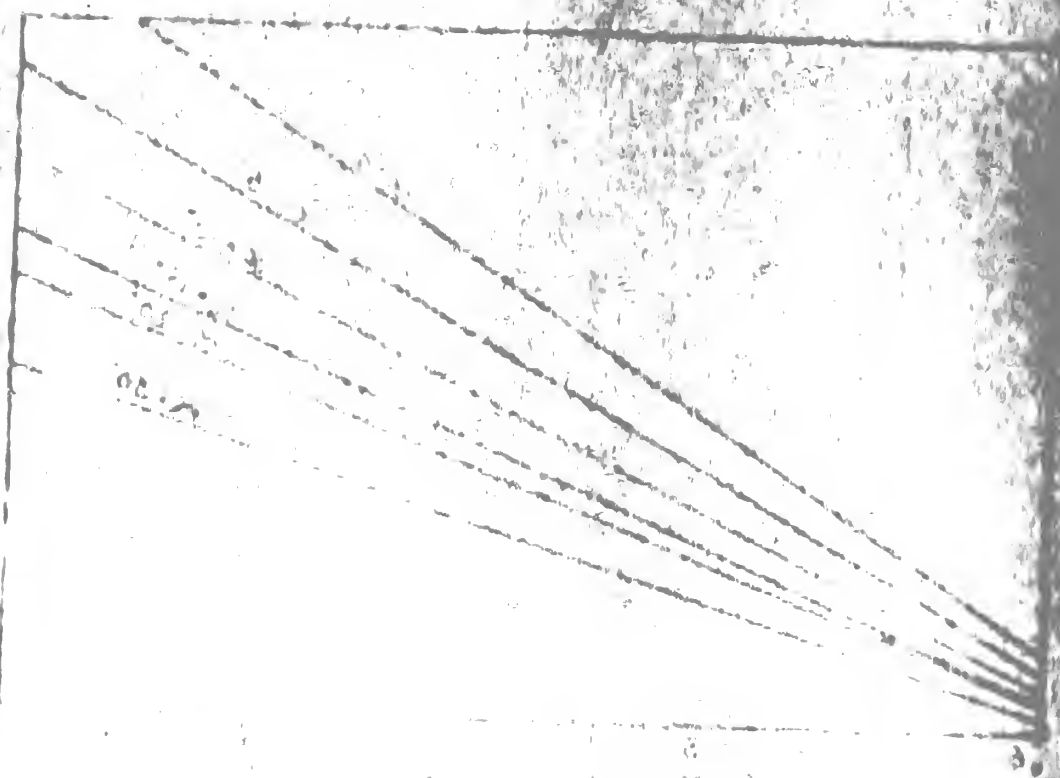
Referring to Figure 5, there are four waves considered. Those numbered 1 and 2 travel towards the open end. Wave 1 is exponentially attenuated and is of the  $T_0$  mode, while wave 2 is propagated with little or no attenuation and is of the  $T_1$  mode. At the open end wave 2 is reflected giving rise to waves 3 and 4 in the reverse direction, wave 4 ( $T_1$  mode) being constant and wave 3 ( $T_0$  mode) exponentially attenuated. In determining the standing wave ratio, since wave 4 is less in magnitude than wave 2, the current minima are not zero in the middle region of the helix. The SWR may be taken as [I2]

$$SWR = \frac{I_2 + I_4}{I_2 - I_4},$$

where the I's are the currents associated with each wave.

Since  $I_2$  is greater than  $I_4$ , and  $I_3$  and  $I_1$  are confined to the ends of the helix, it is possible to calculate the approximate radiation pattern of a long helix on the assumption that only a single traveling wave (2) is present. This radiation pattern calculation has been developed and presented by Kraus [I2]. Kornhauser [4] has derived a rigorous expression for

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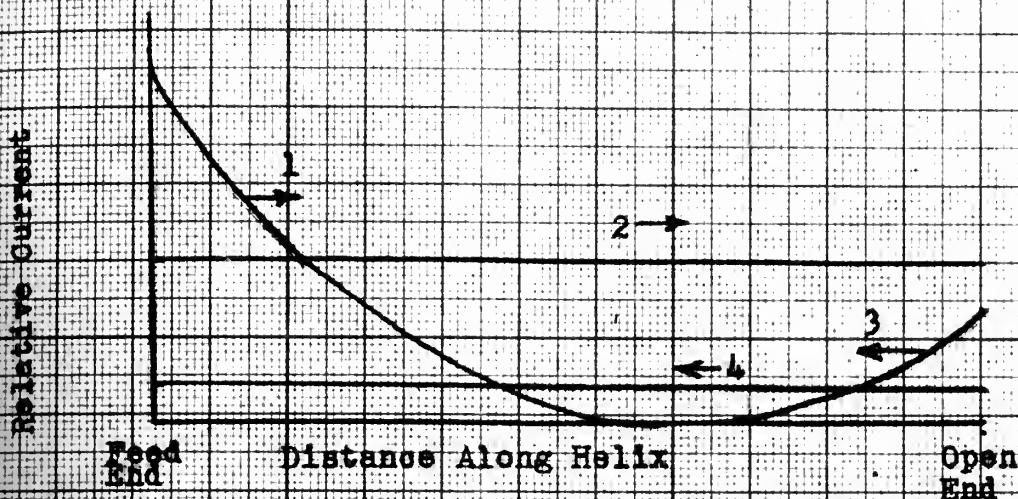


Figure 5. Resolution of Current Distribution on Helix Radiating in the Axial Mode (Courtesy of the American Institute of Physics)

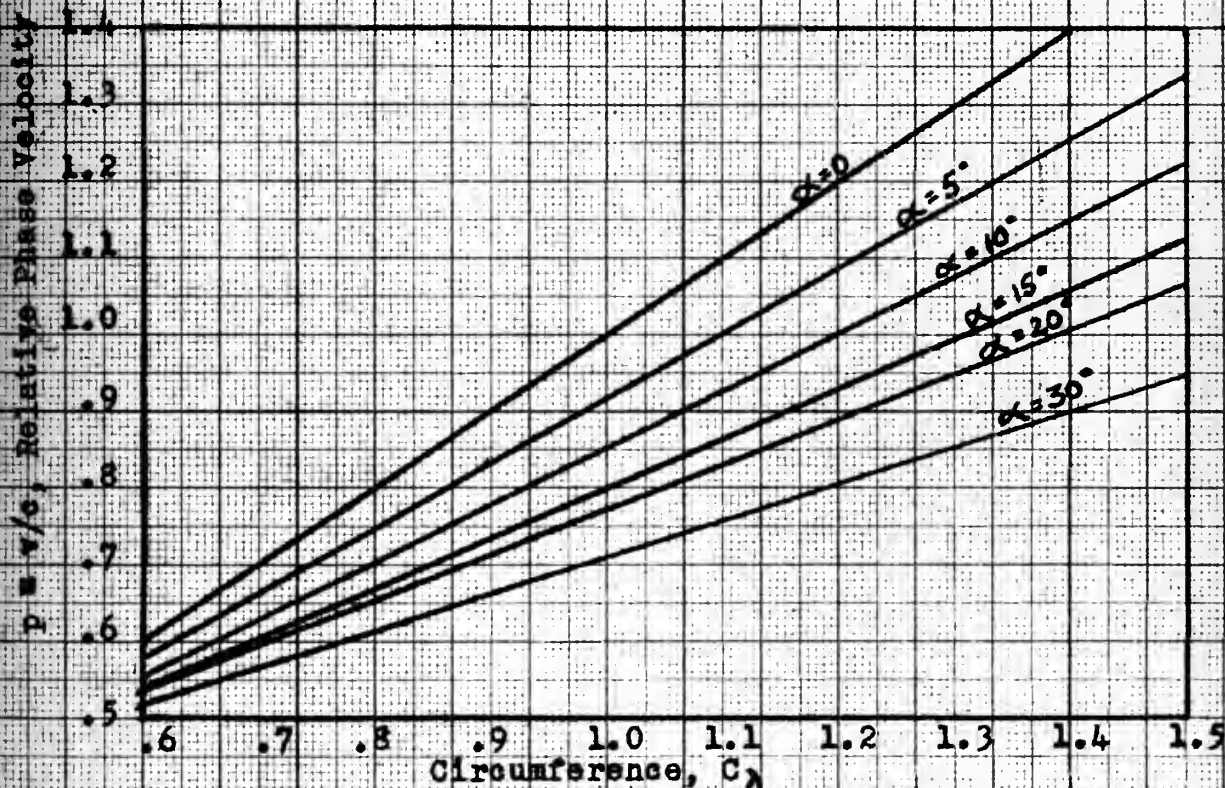


Figure 6. Relative Phase Velocity,  $p$ , for Different Values of Pitch Angle,  $\alpha$ , as a Function of Circumference,  $C_\lambda$ , for the Condition of In-Phase Fields in the Axial Direction. (Courtesy of McGraw-Hill Book Co., Inc.)

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the radiation field presuming this same current distribution. This expression, though somewhat more complex than that of Kraus, is at least more complete and applicable to helices of integral or non-integral numbers of turns. In both cases the approximate current distribution of a single traveling wave seems somewhat unrealistic in that the boundary conditions at the ends of the wire cannot be satisfied. Also the effect of the ground plane is always neglected. However, both of these expressions provide means of calculating the patterns which are very close to those observed experimentally.

When the helix radiates in the axial mode, the phase velocity of wave propagation on the helix adjusts itself so as to make the component electric fields from each turn of the helix add nearly in phase in the direction of the helix axis. The phase velocity variation is shown in Figure 6 [5]. This self adjustment of the phase velocity accounts for the persistence of the axial mode radiation pattern over a relatively wide frequency range. The relative phase velocity,  $p$ , for the axial mode radiation is given by the expression [8]

$$p = \frac{L_{\lambda}}{S_{\lambda} \neq 1}.$$

This expression for in phase fields is referred to as the condition of maximum directivity. Kraus [9] has presented a helix theorem which states:

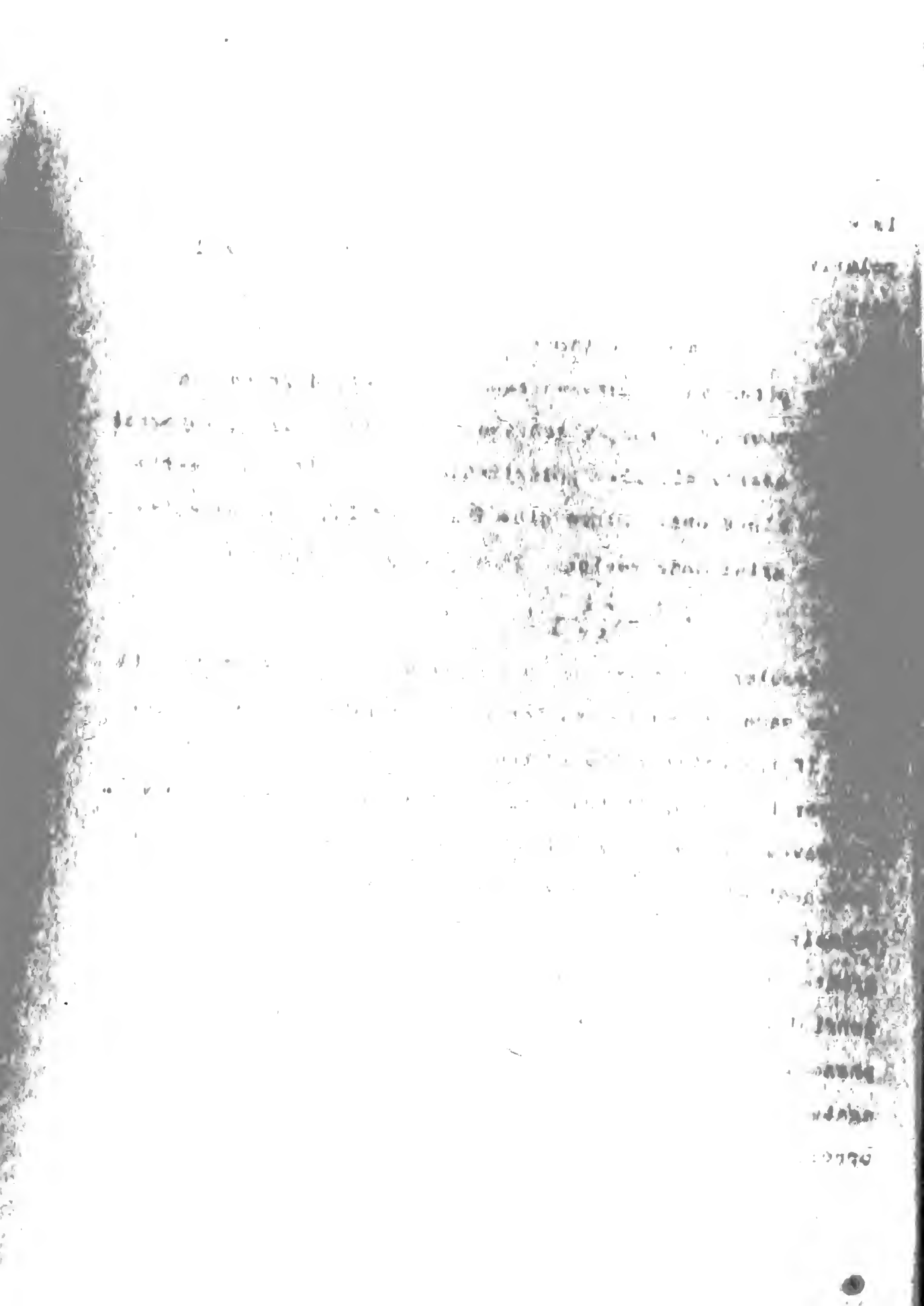


When the circumference of an axial or end-fire helix is about one wavelength ( $T_1$  transmission mode dominant) there is a band of frequencies over which the phase velocity of wave propagation on the helix tends towards a value that makes the directivity a maximum.

Figure 3 is the diameter-spacing chart for the helix showing relative dimensions in wavelengths for the normal and axial modes. The axial mode region may be seen to extend over a relatively large range.

From symmetry it appears that when one traveling wave is present on a long helix, the radiation in the direction of the axis is circularly polarized. Consider a traveling wave on a helix whose circumference is approximately one wavelength. At a given instant of time regions of positive and negative electric charge appear at opposite ends of a diameter. As time proceeds these regions of charge travel along the helix, causing the field to rotate, making one revolution per cycle. Thus on the axis of the helix circular polarization is observed.

The ratio of the major to the minor axis of the polarization ellipse of the electric field intensity is by definition the axial ratio. An axial ratio of one means circular polarization, whereas an infinite axial ratio denotes a plane polarized wave. Circular polarization requires two relations between the crossed fields in a wave. They must be of equal intensity and in phase quadrature. The direction of rotation



of the polarization depends on the phase sequence of the crossed components of either field. Polarization is right or left-handed depending on the direction in which the helix is wound. Kraus [8] has shown the conditions for circular polarization on the axis of the helix in the axial mode.

With

$$k = L_{\lambda}(\sin\alpha - \frac{1}{p}),$$

for any pitch angle between zero and ninety degrees, and a large number of turns, which are not necessarily an integral number, nearly circular polarization occurs if  $k$  is nearly plus or minus one. Since  $\sin\alpha \leq 1$  and  $\frac{1}{p} \geq 1$ ,  $k$  is negative for the axial mode region. Thus  $p$  must be given by

$$p = \frac{L_{\lambda}}{S_{\lambda} - 1},$$

for circular polarization on the axis. This may be seen to be the same expression as for in phase fields given above.

If the axial ratio in the direction of the axis is greater than one, it indicates the presence of other traveling waves on the helix which produce a circularly polarized component with an E-vector rotation opposite to that of the principal component. The observed axial ratio is usually greater than one. Referring once again to Figure 5, and confining the discussion to the constant waves 2 and 4, the phenomenon may be explained by assuming that each wave propagates oppositely polarized circular fields, wave 4 being opposite to 2 and smaller by a reflection process. The pres-

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ence of two circularly polarized waves is derived from the field equations in Appendix I.

The axial ratio of an elliptically polarized field is composed of two oppositely polarized circular components and may be expressed by [I2]

$$A.R. = \frac{E_R + E_L}{E_R - E_L},$$

where  $E_R$  is a wave circularly polarized in a right hand direction and  $E_L$  is in a left hand direction. Wave  $E_R$  is assumed to result from wave 2, the largest in magnitude, and  $E_L$  from wave 4. Thus it would appear that circularity is improved as the magnitude of the reflected wave is reduced.

1. The first part of the document is a list of names and addresses, which are arranged in a columnar fashion. The names are written in a cursive script, and the addresses are written in a more formal, printed style. The list includes names such as "John Doe", "Jane Smith", and "Robert Brown", and addresses such as "123 Main Street", "456 Elm Street", and "789 Oak Street".

2. The second part of the document is a list of names and addresses, which are arranged in a columnar fashion. The names are written in a cursive script, and the addresses are written in a more formal, printed style. The list includes names such as "John Doe", "Jane Smith", and "Robert Brown", and addresses such as "123 Main Street", "456 Elm Street", and "789 Oak Street".

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## CHAPTER III

### DESIGN OF THE HELICAL ANTENNA

A helix may be easily excited in the axial mode in a variety of arrangements. The simplest method is by connecting one end of the helix to the inner conductor of a coaxial line at a point where the outer conductor of the line is terminated in a ground plane of sufficient diameter. This ground plane may be flat as shown in Figure 1, or may be conical or parabolic in shape to focus the radiated beam. In the beam mode of operation the axial component of the electric field is substantially zero along the helix axis which permits placing a conductor along the axis with little change in characteristics. The folded helix employs two helices wound in opposite directions, connected in series, and placed side by side with one helix terminated at the ground plane. Another variation is the double layer helix in which two helices of unequal diameters and opposite screw directions are placed with coincident axes and connected in series, with the outer helix terminated in the ground plane. Other helices employ variable pitch, variable spacing, or tapered diameter to obtain a better axial ratio. However all of the above described arrangements, except the one shown in Figure 1, are difficult to manufacture, particularly at microwave frequencies. There-

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fore discussion will be limited to the simple, uniform helix.

In determining the dimensions to be used in designing the helix, certain factors must be taken into consideration. The beamwidth, gain, and axial ratio are interdependent. The gain is directly proportional to the number of turns of the helix,  $n$ , whereas the beamwidth is inversely proportional to the square root of  $n$ . The axial ratio may be shown to be given approximately by the expression [5]

$$A.R. = \frac{2n \sqrt{1}}{2n},$$

when the relative phase velocity on the helix is such as to fulfill the maximum directivity condition.

On the basis of experimental data, the following dimensions are presented [5] as affording small side lobes, a sharp pattern, and little radiation resistance variation over the bandwidth. The symbols refer to those used in Figure 1, and the wavelength is based on the center frequency.

$$\begin{aligned} D &= 0.32 \lambda \\ S &= 0.22 \lambda \\ C &= 1.00 \lambda \\ g &= 0.12 \lambda \\ G &= 0.80 \lambda \\ d &= 0.02 \lambda \end{aligned}$$

Empirical formulae have been presented [5] to calculate gain, terminal impedance, and beamwidth. The beamwidth between half power points,  $\beta$ , is given by

$$\beta = \frac{52}{\frac{C}{\lambda} \sqrt{\frac{S}{\lambda}}},$$



and the power gain with respect to an isotropic circularly polarized source by

$$\text{Gain} = 15(C_\lambda)^2 n S_\lambda.$$

As long as  $n$  is greater than three,  $\alpha$  is between 12 and 15 degrees, and  $C$  lies between  $3/4$  and  $4/3$  wavelengths, the terminal impedance is nearly pure resistance and is given by

$$R = 140 C_\lambda \text{ ohms.}$$

1944  
The following is a list of the names of the persons who were present at the meeting held on the 1st day of January, 1944, at the residence of Mr. J. H. Smith, 1234 Main Street, New York City.  
The names of the persons present are as follows:  
Mr. J. H. Smith  
Mr. A. B. Jones  
Mr. C. D. Brown  
Mr. E. F. Green  
Mr. G. H. White  
Mr. I. J. Black  
Mr. K. L. Gray  
Mr. M. N. Blue  
Mr. O. P. Red  
Mr. Q. R. Purple  
Mr. S. T. Yellow  
Mr. U. V. Orange  
Mr. W. X. Pink  
Mr. Y. Z. Brown  
The names of the persons who were absent are as follows:  
Mr. A. B. Jones  
Mr. C. D. Brown  
Mr. E. F. Green  
Mr. G. H. White  
Mr. I. J. Black  
Mr. K. L. Gray  
Mr. M. N. Blue  
Mr. O. P. Red  
Mr. Q. R. Purple  
Mr. S. T. Yellow  
Mr. U. V. Orange  
Mr. W. X. Pink  
Mr. Y. Z. Brown  
The names of the persons who were present at the meeting held on the 2nd day of January, 1944, at the residence of Mr. J. H. Smith, 1234 Main Street, New York City, are as follows:  
Mr. J. H. Smith  
Mr. A. B. Jones  
Mr. C. D. Brown  
Mr. E. F. Green  
Mr. G. H. White  
Mr. I. J. Black  
Mr. K. L. Gray  
Mr. M. N. Blue  
Mr. O. P. Red  
Mr. Q. R. Purple  
Mr. S. T. Yellow  
Mr. U. V. Orange  
Mr. W. X. Pink  
Mr. Y. Z. Brown  
The names of the persons who were absent are as follows:  
Mr. A. B. Jones  
Mr. C. D. Brown  
Mr. E. F. Green  
Mr. G. H. White  
Mr. I. J. Black  
Mr. K. L. Gray  
Mr. M. N. Blue  
Mr. O. P. Red  
Mr. Q. R. Purple  
Mr. S. T. Yellow  
Mr. U. V. Orange  
Mr. W. X. Pink  
Mr. Y. Z. Brown

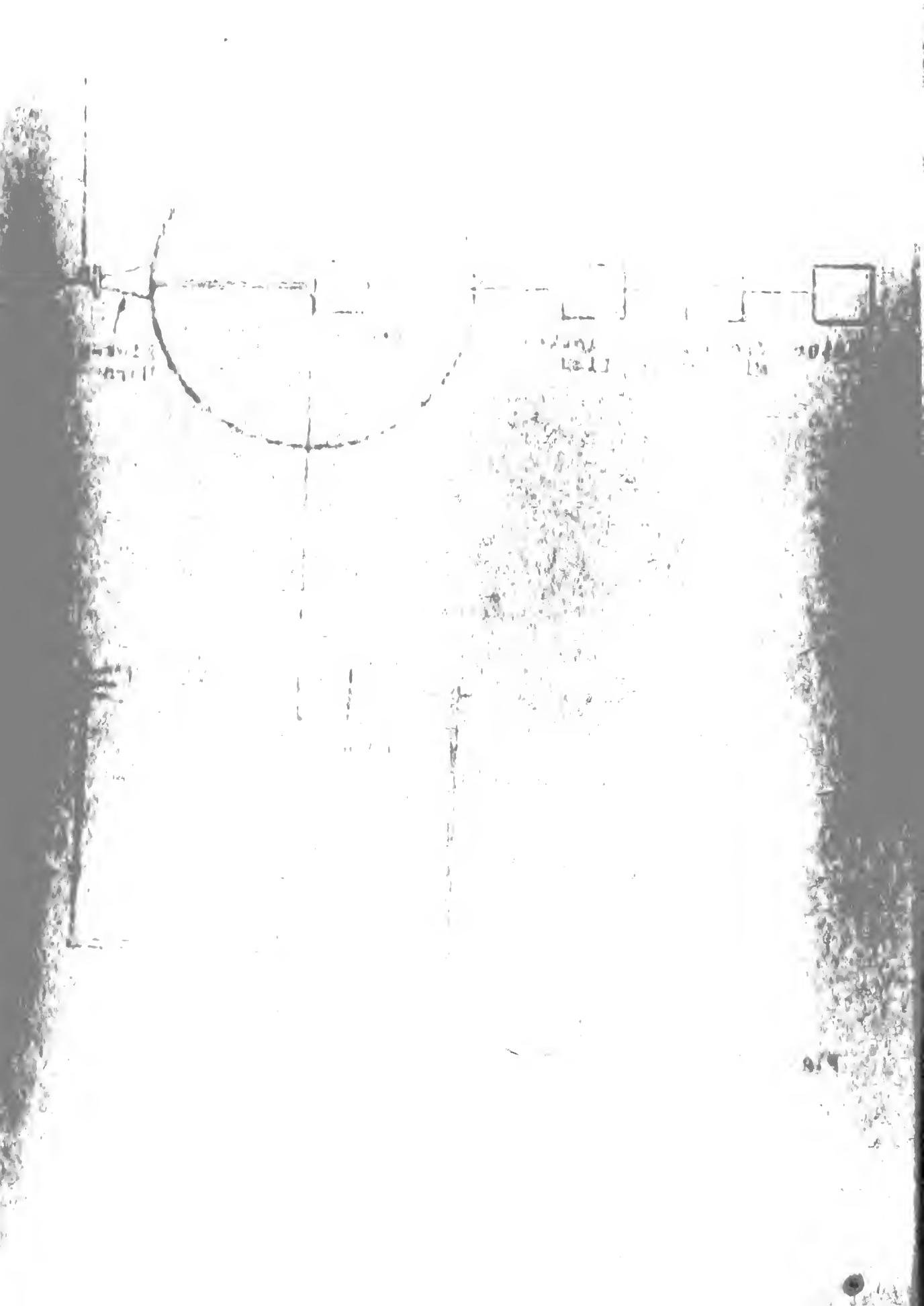


## CHAPTER IV

### MEASUREMENT TECHNIQUES

Before proceeding to the discussion of the helical antenna at K band, it might be best to explain how the measurements discussed are made. Figure 7 shows a block diagram of the equipment used to measure the antenna's characteristics. The oscillator employed is a V-90 klystron. A slotted line is used to measure the VSWR in the waveguide. The helical antenna is set over the center of a horizontal arm having a swing of almost 360 degrees. The pick-up horn, mounted on this horizontal arm, is directly on axis with the helix and can be moved about a vertical axis to any angle in a horizontal plane at a constant radius from the end of the antenna. The pick-up horn itself can be rotated through 360 degrees on a horizontal axis. These two degrees of rotational freedom for the pick-up horn permit the taking of data from which the axial ratio and the radiation pattern may be obtained.

For field pattern measurements of greater accuracy, an anechoic chamber is used. The transmitting horn is stationary in the same horizontal plane as the receiving helical antenna. The helix can be rotated in a horizontal plane by means of an accurately controlled turntable. A



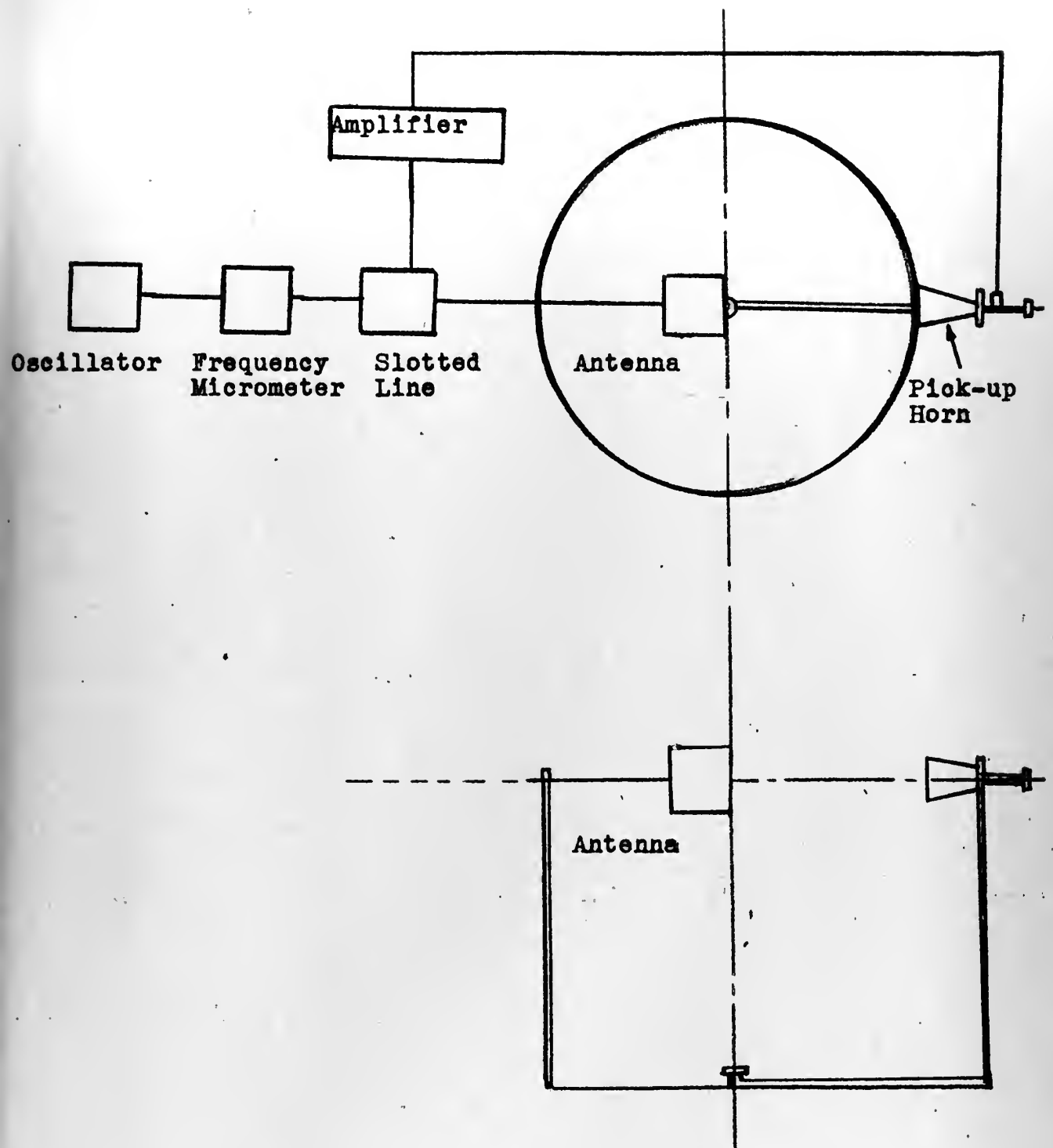


Figure 7. Block Diagram of Measuring Equipment



vernier on the turntable permits reading the angle offset to 0.1 degree. The end of the helix is directly over the center of the turntable, i.e. on the vertical axis about which the turntable is rotated. The helix can also be rotated 360 degrees about its own axis to facilitate obtaining the axial ratio.

In both methods the receiving antenna is connected to a crystal mount and the signal sent to an amplifier where the voltage is read. The axial ratio is the ratio of the maximum to the minimum voltages read as the receiving antenna is rotated on its horizontal axis through 360 degrees.

The patterns presented in this investigation were obtained in an anechoic chamber and were measured in the planes of maximum and minimum radiation. These patterns were made at the mid-frequency and at the upper and lower ends of the prescribed bandwidth. In all measurements great care had to be exercised to align the axes very accurately.

488

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no = 11



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## CHAPTER V

### EXPERIMENTAL PROCEDURE

The physical dimensions of the helix at K band are so small that some means of support must be provided for proper rigidity of the helical structure. It was decided to wind the helix on a polystyrene form, i.e. a cylindrical rod threaded for the desired pitch and helix diameter. Polystyrene was selected because of its low dissipation factor. It is also relatively easy to machine. A helix wound on such a rod operates in two mediums, polystyrene within the helix and free space without. Thus a shell is employed to surround the form such that the helix is embedded in a continuous medium of known dielectric constant. The dimensions of the helix are therefore  $1/\sqrt{\epsilon}$  times the free space dimensions, where  $\epsilon$  is the dielectric constant of polystyrene. If the shell is made to extend over the end of the helix excessively, it tends to act as a dielectric rod antenna, and thereby to restrict the beamwidth of the radiation pattern. It can also effect the axial ratio by causing a poor match at the end of the helix. A poor match produces a reflected wave, oppositely polarized, and traveling towards the feed end. The greater the magnitude of the reflected wave, the higher the axial ratio. Experiment shows that extending the shell approximate-





ly  $2S_{\lambda}$  over the last turn of the helix gives satisfactory results.

Several attempts were made to feed the helix by a simple probe into the waveguide. A circular ground plane was soldered on the broad side of the waveguide. The cylindrical rod on which the antenna was wound was fitted snugly into a hole through the center of the ground plane and the waveguide's wall. The probe was led coaxially through this hole and coupled to the E field in the guide. A tuning stub terminated the guide approximately ten wavelengths from the probe. Various arrangements were made with this feed and some successful patterns resulted. However, it was found that duplicating the characteristics of an antenna was virtually impossible since the position of the probe was so critical. Any slight bend in the probe or variation of depth caused considerable differences in the radiation pattern. This same undesirable condition prevails when the helix is grounded to the waveguide, and also when a loop type feed is employed. A great deal of time was spent in trying to get consistency in readings taken between various antennas which were supposedly the same. It finally became apparent that it was not possible to manufacture two antennas having the same characteristics when a probe or loop pick-up was used.



Next the feed was altered by eliminating the probe and simply extending the helix into the waveguide. This is very similar to a method employed to energize the helix in a traveling-wave tube [14]. The radiation pattern was very dependent upon the orientation and depth of the helix into the guide, but the results were reproducible from one antenna to another. The difficulty in this method is the frequency sensitivity. As the frequency was varied it was necessary to retune the adjustable short terminating the waveguide in order to obtain the desired characteristics.

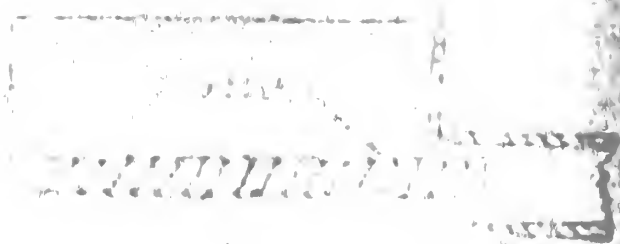
Finally it was decided to use an end-fire feed system, extending the helix into the end of the waveguide, and thereby eliminate the tuning stub. A wave traveling towards the end of the waveguide is picked up by the helical feed and this initiates a propagating wave on the helical structure. Once again the depth of the helix into the waveguide effects the characteristics, but three turns was selected as the optimum and the results were found satisfactory. This agrees with a statement by Haycock and Ajloka [2] that at least three turns are necessary to obtain circular polarization. A bandwidth of 600 megacycles was required and easily obtained using this feed. Figure 8 shows the construction of the antenna. A polystyrene tapered section was added to improve the match of the antenna to the waveguide.



PORTAL, 2001, 2010



2001, 2010, 2011



2001, 2010, 2011

2001, 2010, 2011

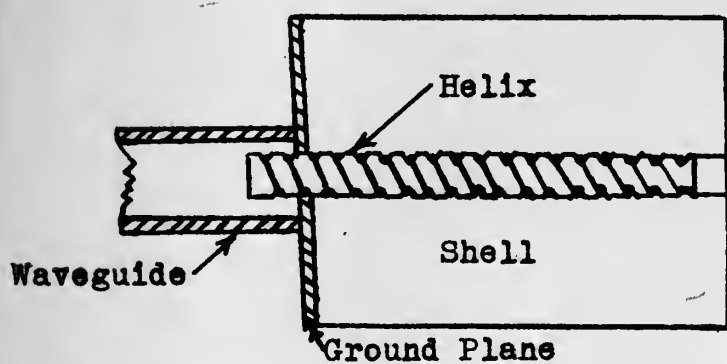
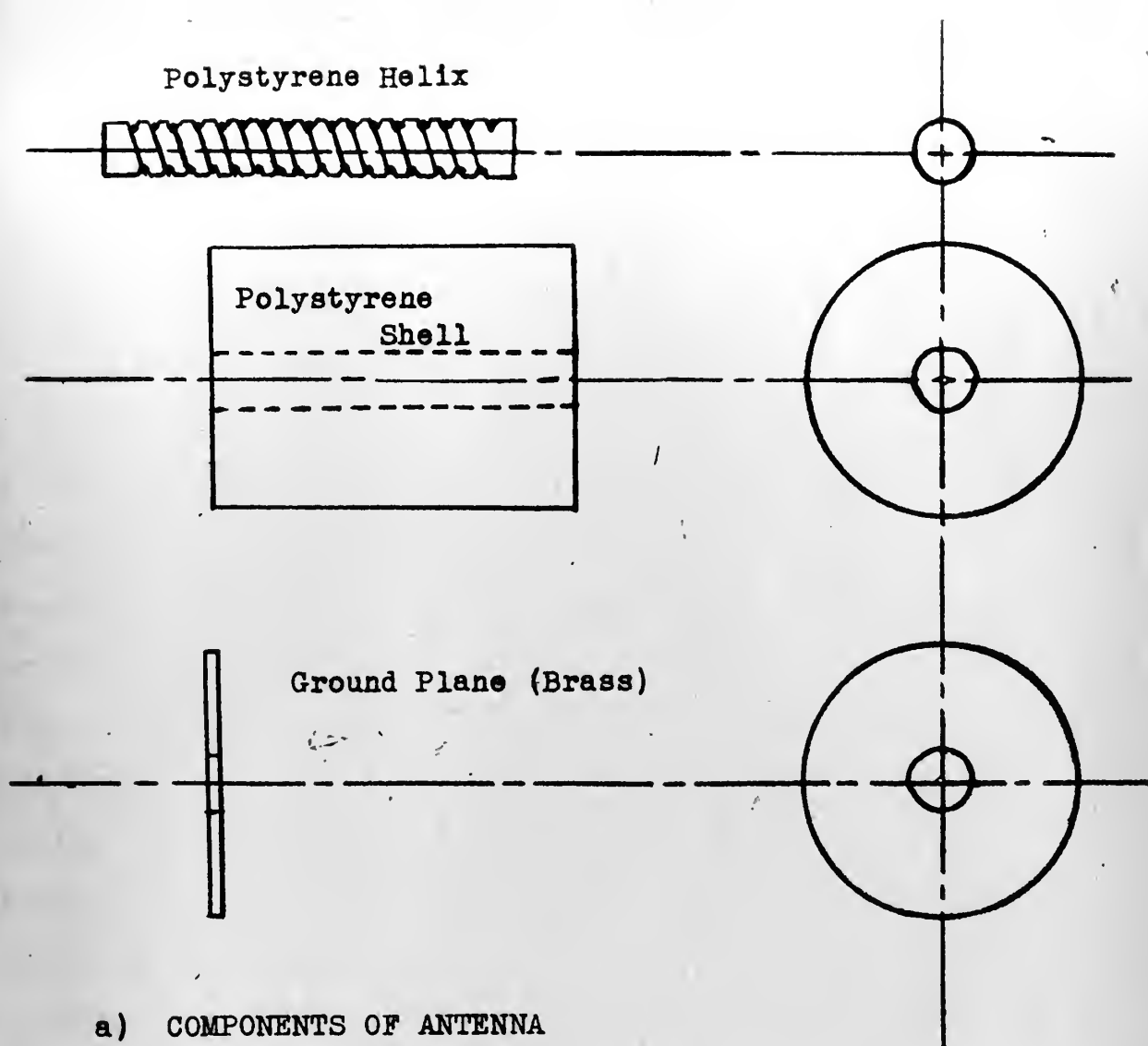
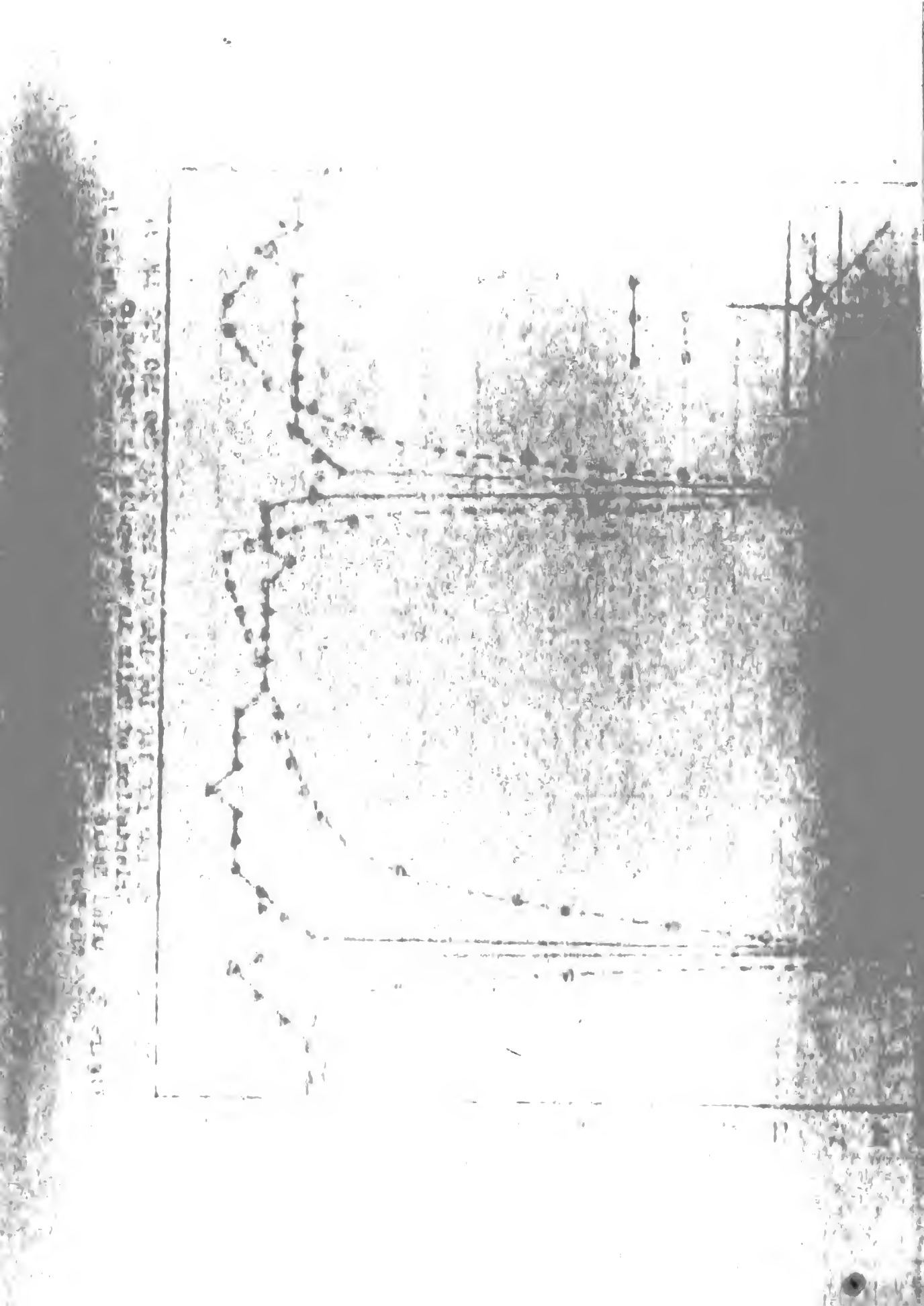


Figure 8. K Band Antenna Assembly



Results show that the position of the ground plane is extremely critical. It is necessary to have the ground plane exactly perpendicular to the end of the waveguide. Orientation of the helix within the waveguide is also critical since, for a given depth, the axial ratio and match vary as the helix is rotated on its axis. This fact is not mentioned in the literature on traveling-wave tubes or helical structures, therefore curves are presented in Figure 9, which show for a constant depth of three turns into the waveguide plots of orientation versus VSWR in the waveguide and axial ratio to two significant figures. It is interesting to note that at one angle, and 180 degrees from it, the polarization is essentially linear, and the VSWR is very high. The angle indicated on the abscissa is that between the top of the waveguide and the end turn of the helix, going clockwise as the antenna is viewed outside the waveguide. The helix itself is a right-hand winding.





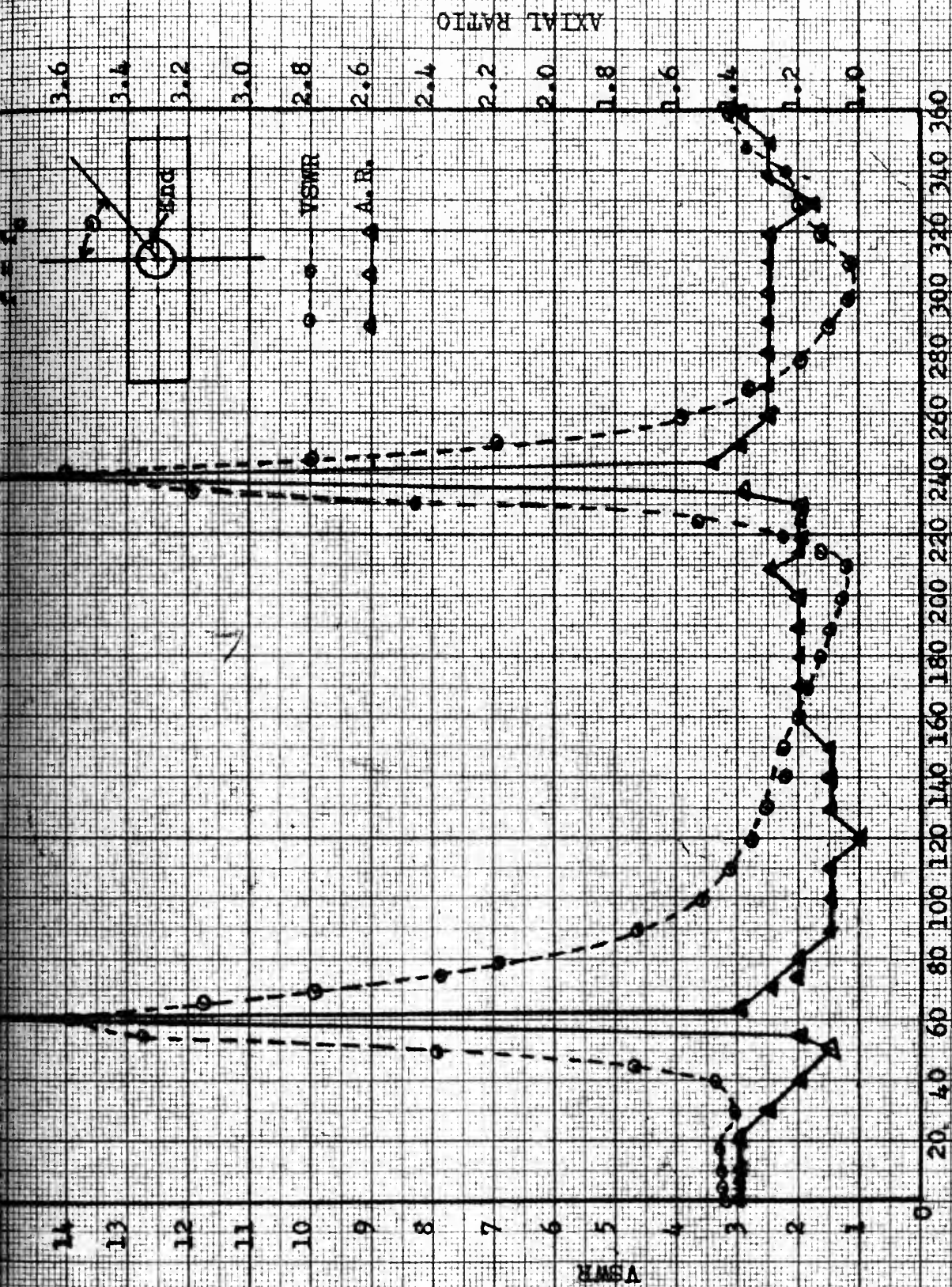


Figure 9. Axial Ratio and VSWR Variation with Orientation of Helix in the Waveguide. Depth of Helix in guide = 3 turns (Experimental)



## CHAPTER VI

### THE EFFECT OF MATCH ON AXIAL RATIO

Considering the results shown by Figure 9, it appears reasonable to expect the match and axial ratio to become poor simultaneously. Again referring to an early section of this paper, the reflected wave returning to the feed end of the helix is of such magnitude as to make the axial ratio very large. This same wave will effect the match at the input resulting in a large VSWR in the waveguide. This accounts for the magnitude of the axial ratio within the waveguide. Since the helical antenna external to the guide receives its wave from the feed, the radiation pattern is also effected. This may be explained by assuming the following method of propagation.

Assume that a right-hand circularly polarized wave is launched along the helix inside the waveguide and call it  $E_{R1}$ . (A right-hand wave results since the helix is wound in this direction.) When this wave reaches the ground plane a reflection occurs and an oppositely polarized wave,  $E_{L1}$ , travels back along the helix to the input end. The magnitude of  $E_{L1}$  depends on the amount of mismatch the ground plane presents to the first three turns of the helix. At the ground plane a wave continues along the helix external

For the purpose of the present investigation, the following data were collected from the records of the Bureau of the Census, Department of Commerce, and the Bureau of Economic Warfare, Department of War, for the years 1939, 1940, and 1941.

The data were obtained from the following sources: (1) the Bureau of the Census, Department of Commerce, for the years 1939 and 1940; (2) the Bureau of Economic Warfare, Department of War, for the year 1941; and (3) the Bureau of the Census, Department of Commerce, for the year 1941. The data were obtained from the following sources: (1) the Bureau of the Census, Department of Commerce, for the years 1939 and 1940; (2) the Bureau of Economic Warfare, Department of War, for the year 1941; and (3) the Bureau of the Census, Department of Commerce, for the year 1941.

The data were obtained from the following sources: (1) the Bureau of the Census, Department of Commerce, for the years 1939 and 1940; (2) the Bureau of Economic Warfare, Department of War, for the year 1941; and (3) the Bureau of the Census, Department of Commerce, for the year 1941.

to the waveguide which will be designated as  $E_{R2}$ . The ellipticity of  $E_{R2}$  is given by the expression

$$A.R. E_{R2} = \frac{E_{R1} \neq E_{L1}}{E_{R1} - E_{L1}} .$$

As  $E_{R2}$  travels along the external helix it causes a reflected wave,  $E_{L2}$ , at the end. Neglecting second and higher order effects, (i.e. multiple reflections) the waves present on the helix external to the ground plane are  $E_{R2}$  and  $E_{L2}$ . Thus the axial ratio of the radiated wave may be expressed as

$$A.R. = \frac{E_{R2} \neq E_{L2}}{E_{R2} - E_{L2}} .$$

The reflection of  $E_{R2}$  at the end of the helix causes  $E_{L2}$ . Since the reflection occurring at the end of the helix remains essentially independent of the orientation of the helix,  $E_{L2}$  may be expressed as equal to  $kE_{R2}$ , where  $k$  is a constant involving the reflection coefficient and the attenuation factor of  $E_{R2}$ . Therefore the axial ratio of the radiated field may be expressed as

$$A.R. = E_{R2} \frac{1 \neq k}{1 - k} .$$

This shows that the axial ratio is a function of the ellipticity of  $E_{R2}$ , which in turn depends on the match within the waveguide.



Let the reflection which occurs within the guide be designated as  $R$ . This total reflection is the sum of at least three components (by neglecting second or higher order reflections). The first is due to the feed end of the helix; the second is due to the ground plane; and the third is due to the end of the external helix. The reflection occurring at the feed end of the helix will be designated as  $r_1$ , a constant which depends on the coefficient of reflection at that particular point. Reflections  $r_2$  and  $r_3$  are similarly defined for the ground plane and the end of the external helix respectively. The angle,  $\Theta$ , is defined as the angular rotation of the E-vector from the E-vector position in the guide along the helix to the reflection boundary in question. The reflection in the guide may be written as

$$R = r_1 e^{-j\Theta_1} + r_2 e^{-j\Theta_2} + r_3 e^{-j\Theta_3}$$

where the subscripts refer to the above given positions along the helix. Reflection  $r_3$  is constant, however  $r_1$  and  $r_2$  vary as the helix is rotated. The variation of  $r_1$  and  $r_2$  may be explained in terms of the planes in which they occur. The position of the end of the conductor in the guide affects  $r_1$  whereas the position of the conductor in the aperture of the ground plane determines  $r_2$ . Thus it would appear that the effective value of  $R$  depends on the helix







orientation and so determines the axial ratio of the radiated field.

ON 2000 21

W. MAY. 1974

12 11 10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

10 9 8 7 6 5 4 3 2 1

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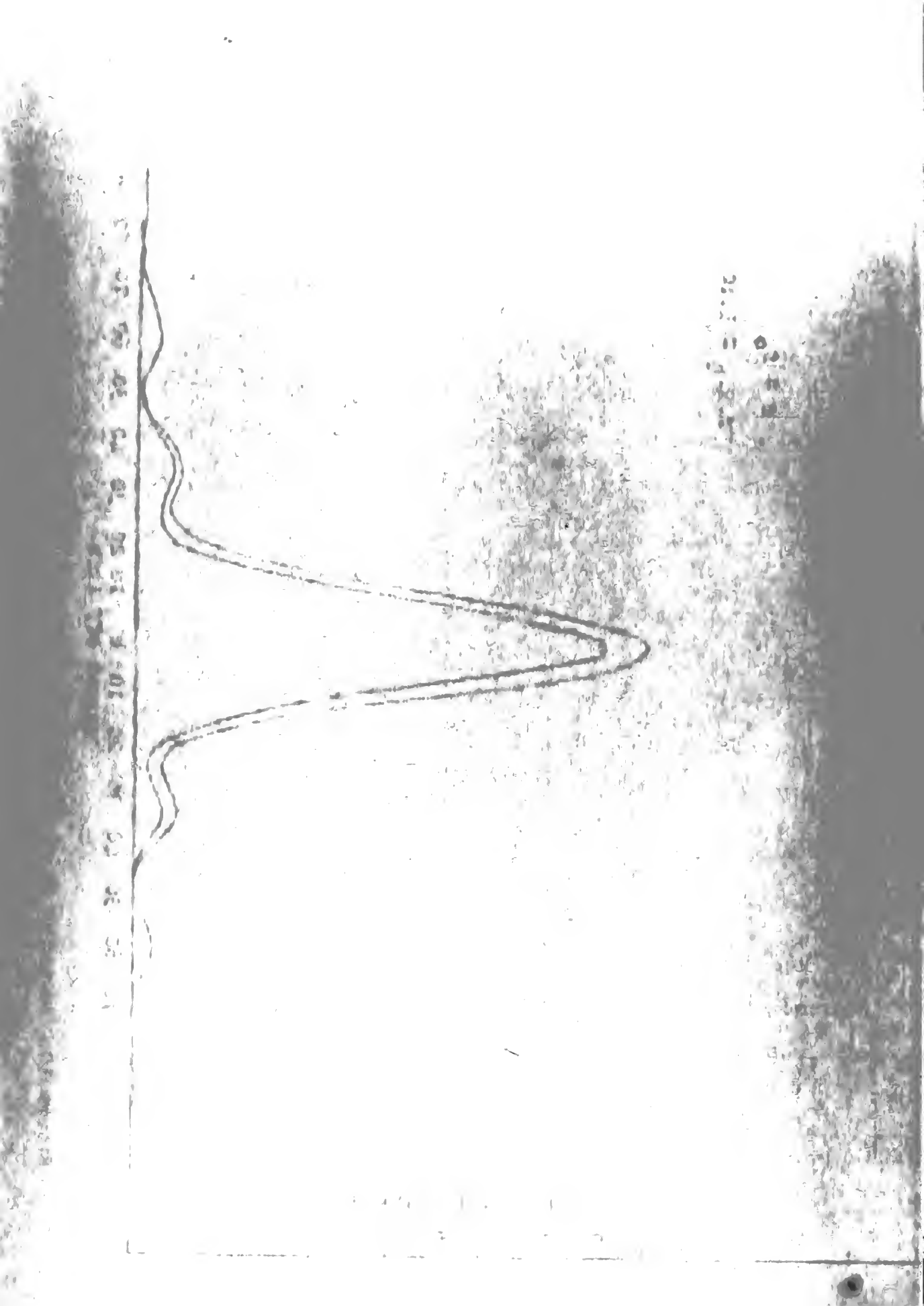
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## CHAPTER VII

### RESULTS AND CONCLUSIONS

The antenna's characteristics are shown in Figures 10 through 13. Figure 10 is the radiation pattern at the center frequency, Figure 11 at 300 megacycles above center frequency, and Figure 12 at 300 megacycles below center frequency. These patterns were taken in an anechoic chamber. The beamwidth between half-power points is 23 degrees over the bandwidth. These patterns compare very well with low frequency helical antenna patterns. The axial ratio is less than 1.25 within the beamwidth over the frequency band. The axial ratios may be determined from the patterns by taking the ratio of the magnitudes of the field intensities at any given point on the pattern.

Figure 13 is a Smith chart plot of impedance versus frequency for the helical antenna at K band. The impedance is relatively constant over the bandwidth. Two extreme points of frequency are plotted which show the tendency for the plot to spiral on itself as has been observed for low frequency helical antennas [10]. The impedance is of the same order of magnitude as for low frequency antennas and almost pure resistance (a ratio of R to X of almost 12 to one) at the center frequency. A measure of true impedance



$f = f_0$   
 $A.R._0 = 1.10$

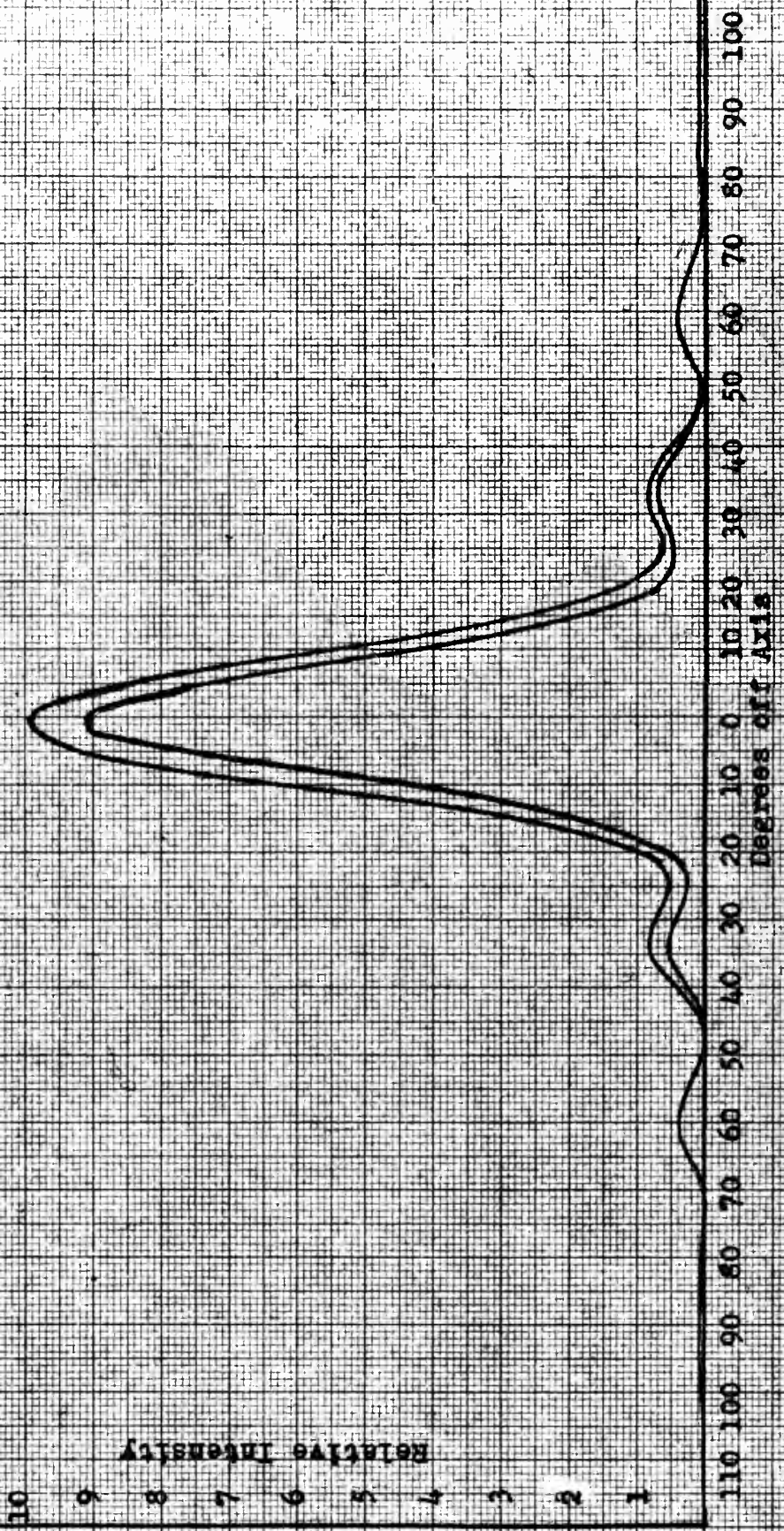
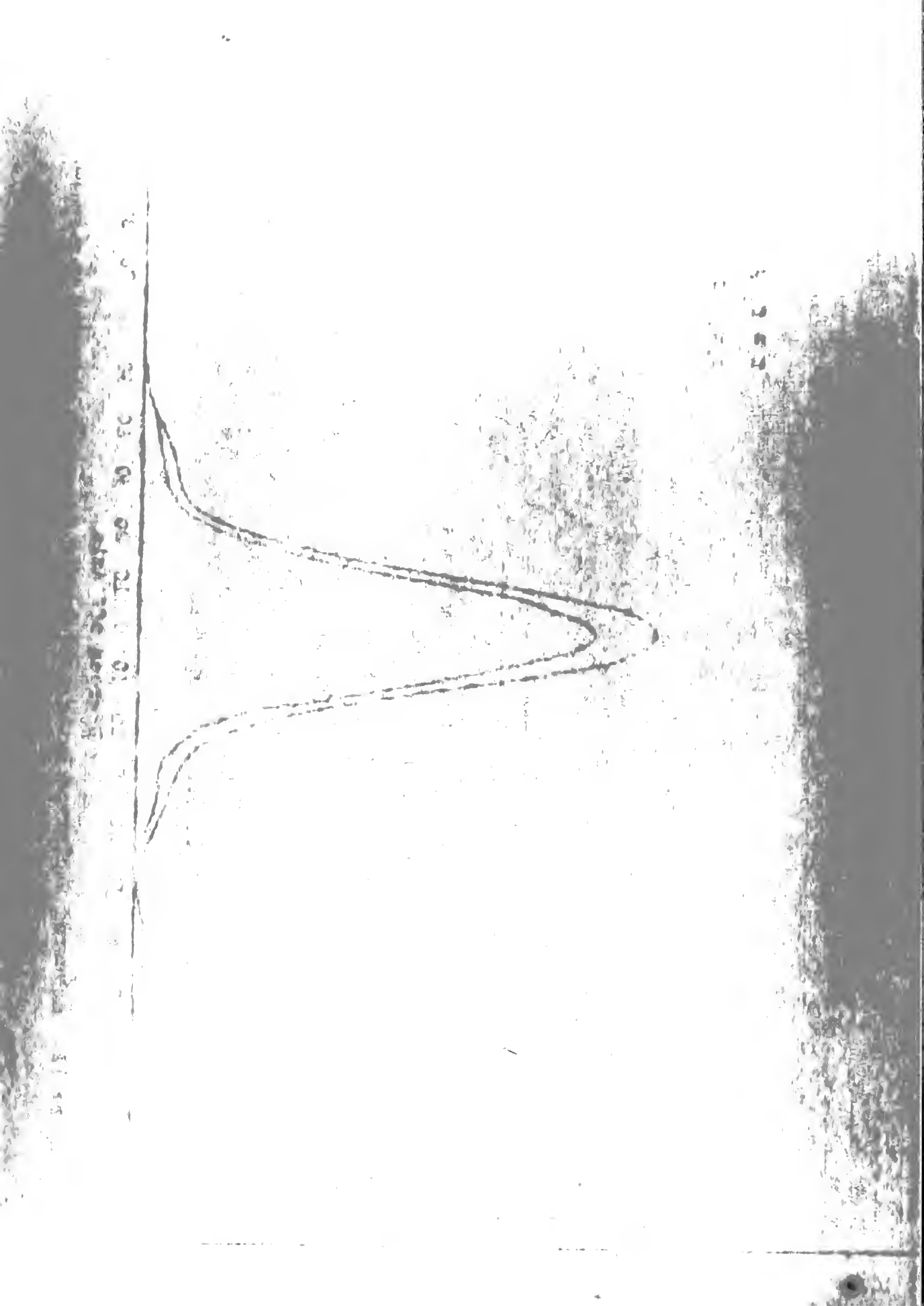


Figure 10. Measured Radiation Pattern at Center Frequency,  $f_0$





$f = f_0 \pm 300 \text{ Mc}$

$A.R.O. = 1.14$

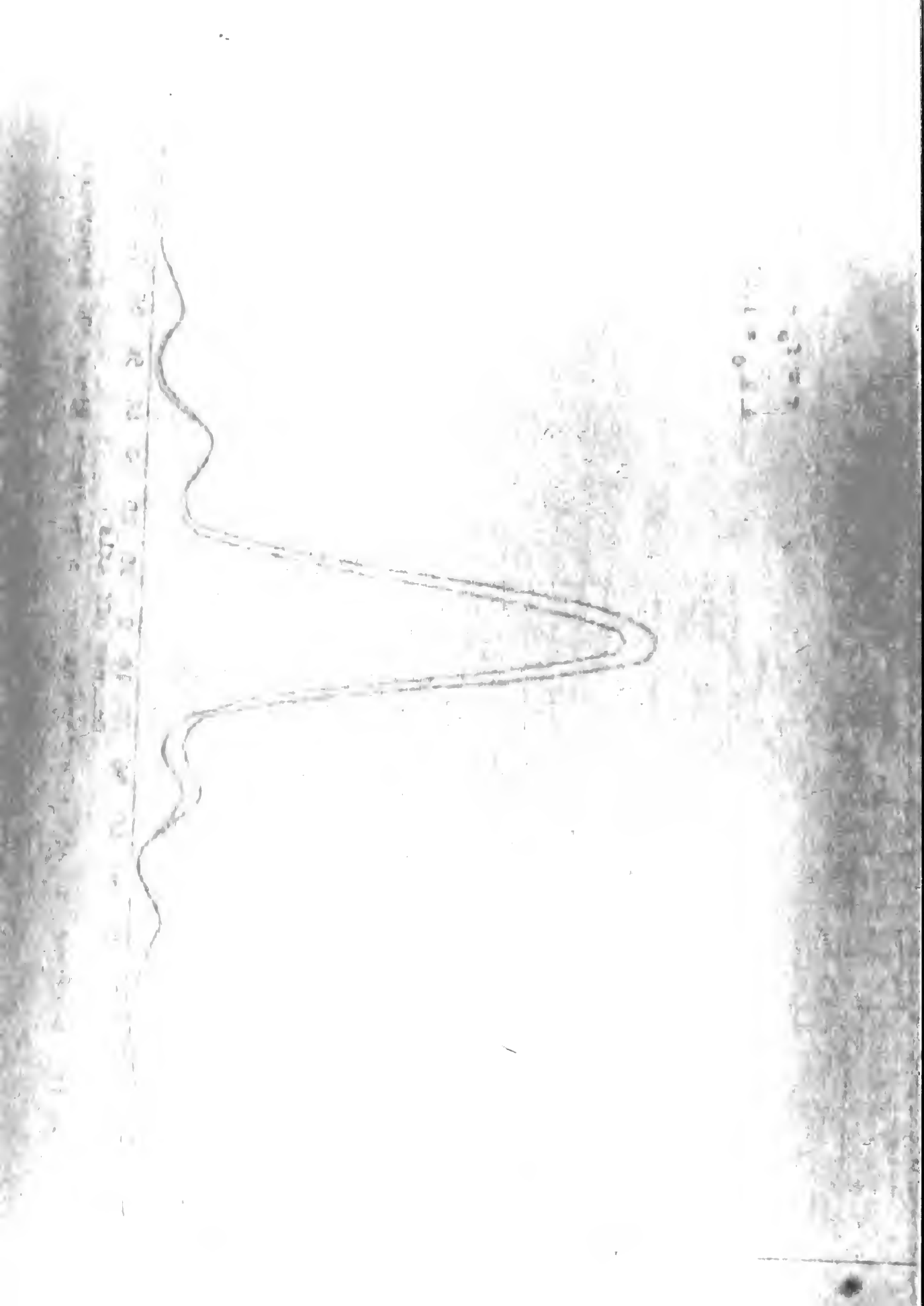
Relative E Intensity

10  
9  
8  
7  
6  
5  
4  
3  
2  
1

120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90

Degrees off Axis

Figure 11. Measured Radiation Pattern at Center Frequency plus 300 Megacycles





$f = f_0 = 300 \text{ MHz}$

A.R.O. = 1.07

Relative Intensity

10  
9  
8  
7  
6  
5  
4  
3  
2  
1

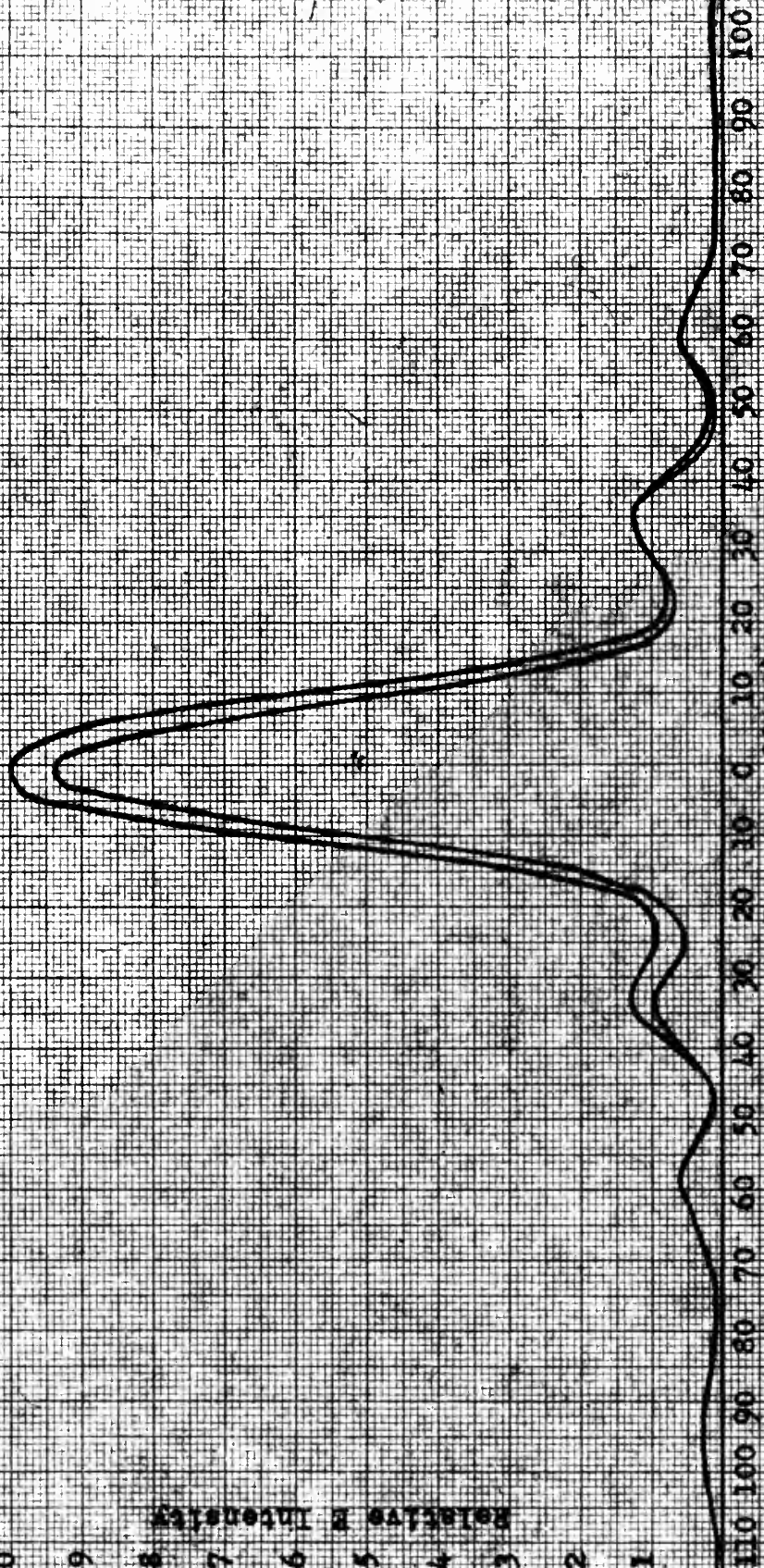
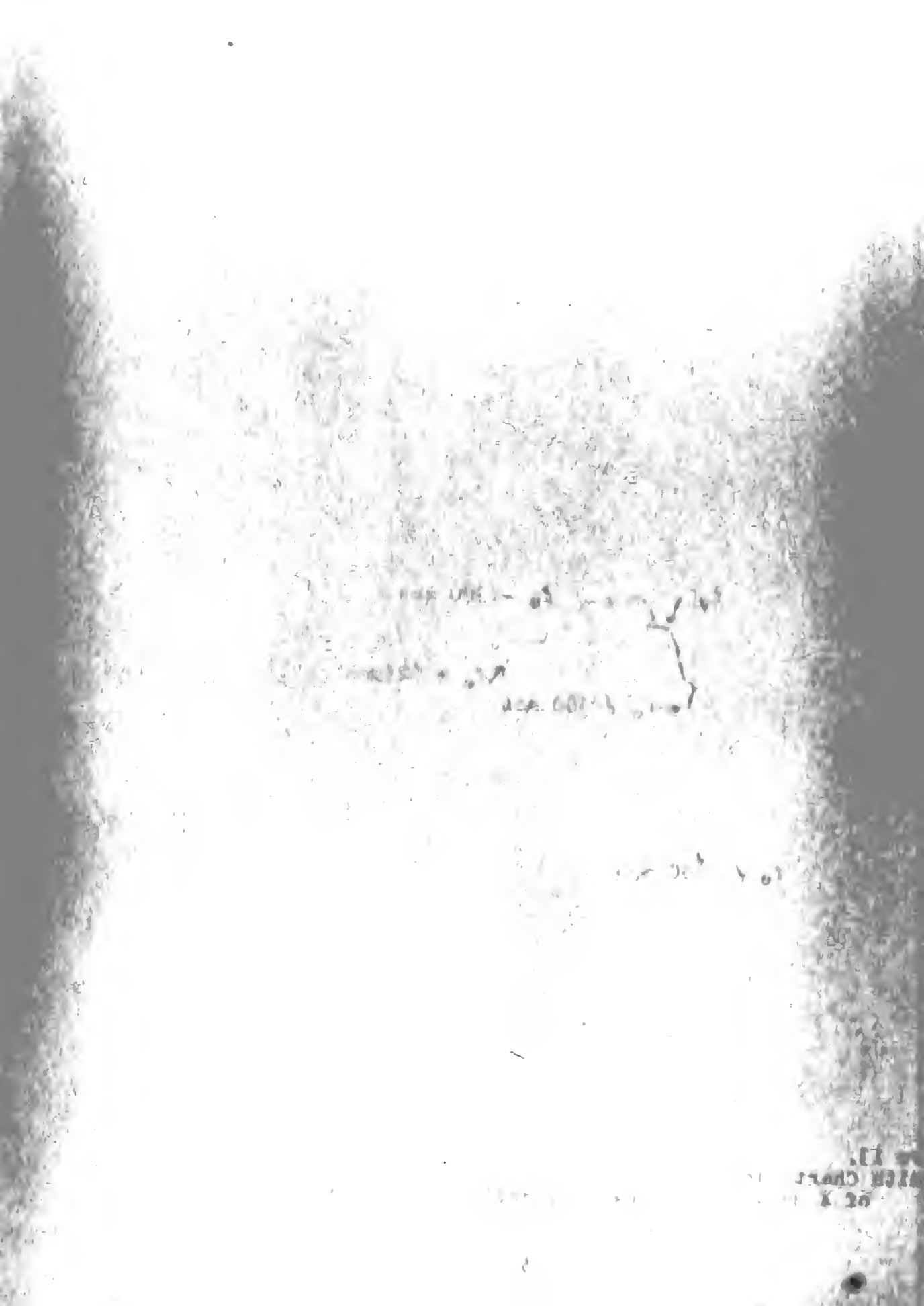


Figure 12. Measured Radiation Pattern at Center Frequency of 300 Megacycles.



## IMPEDANCE OR ADMITTANCE COORDINATES

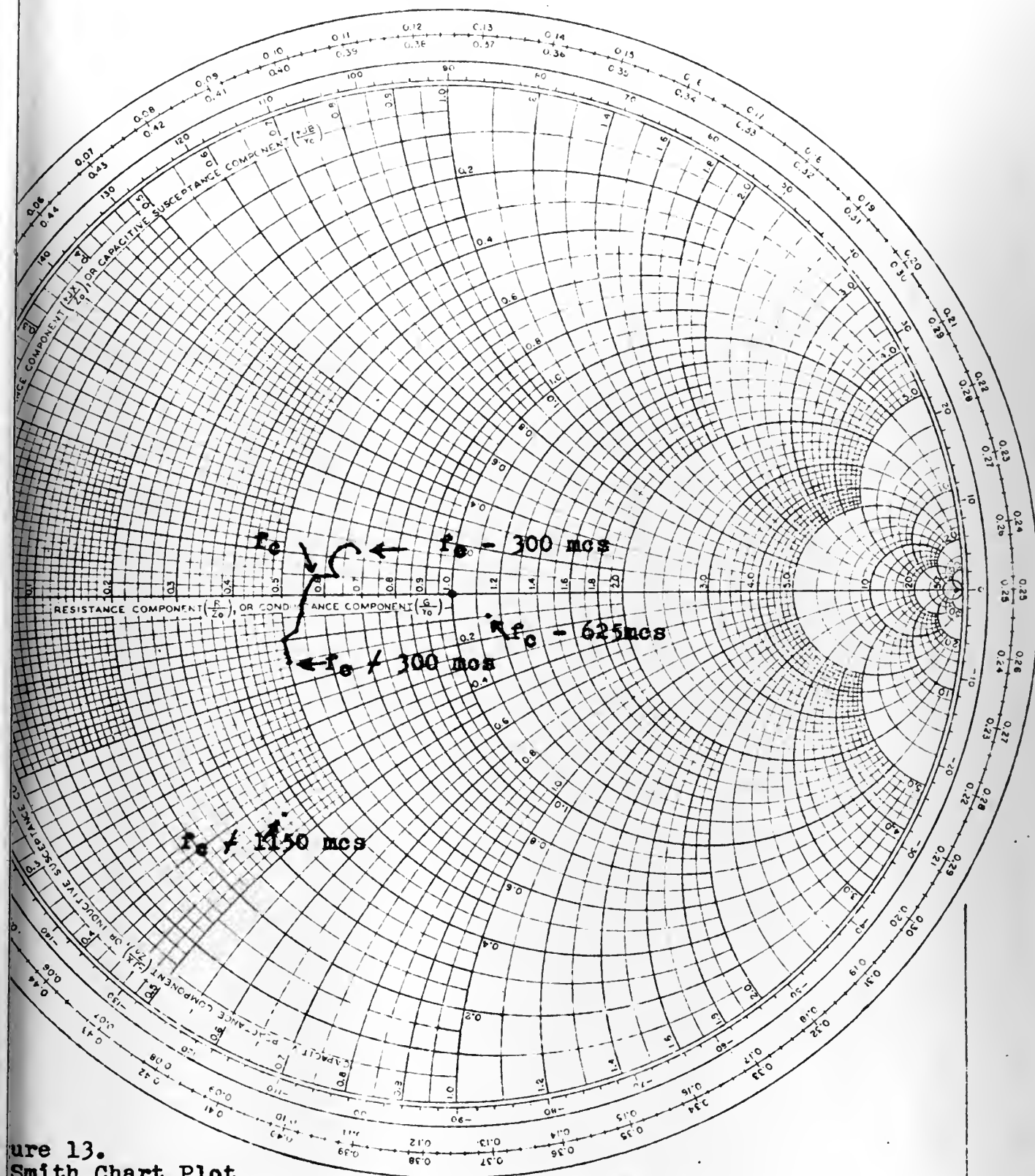
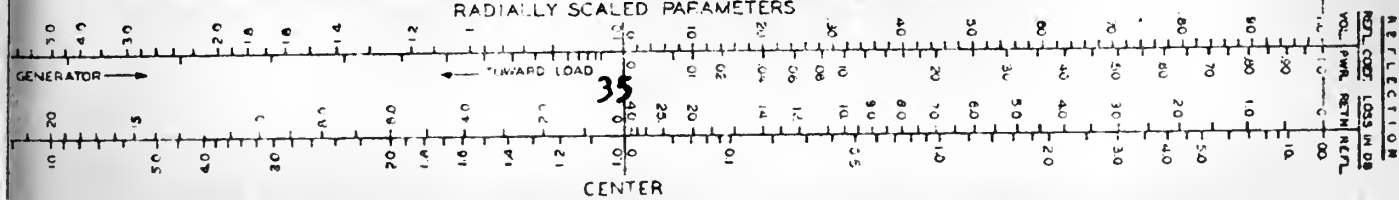


Figure 13.  
Smith Chart Plot  
of K Band Antenna over Prescribed Bandwidth

RADially SCALED PARAMETERS



1. The first of these is the fact that the  
 2. the second is the fact that the  
 3. the third is the fact that the  
 4. the fourth is the fact that the  
 5. the fifth is the fact that the  
 6. the sixth is the fact that the  
 7. the seventh is the fact that the  
 8. the eighth is the fact that the  
 9. the ninth is the fact that the  
 10. the tenth is the fact that the

is difficult because of the polystyrene surroundings and the inability to determine how much of the observed phase shift is due to the helix alone. The observed VSWR in the waveguide was less than 2.0 over the bandwidth.

The helical antenna at K band is feasible and possesses the inherent advantages of a low frequency helical antenna. Extreme precautions must be taken as is to be expected for the microwave spectrum. The most serious problem is that of matching the helix to the waveguide in order to launch a wave on the helix, and this problem is overcome by careful orientation of the helix within the guide as shown in this investigation.

Expenditure

Revenue

Capital

Grants

Interest

Other

10

11



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$$= (x, 0).$$
$$f(x) = \frac{1}{x^2} = x^{-2} \Rightarrow f'(x) = -2x^{-3} = -\frac{2}{x^3}$$

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1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

$$\frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} \right) = \frac{1}{2}$$

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# APPENDIX I

The following expressions were developed by Sollfrey [I5] to give the transverse fields on the helix in rectangular coordinates.

$$E_x(0, z) =$$

$$\frac{-I_0 \sec \alpha (\mu/\epsilon)^{\frac{1}{2}}}{4\pi} \left[ \left\{ p_1 K_1(p_1 a) - k \cos \alpha K_0(p_1 a) \right\} e^{ikz \sec \alpha (1 - 1/k \sec \alpha)} \right. \\ \left. + \left\{ p_{-1} K_1(p_{-1} a) + k \cos \alpha K_0(p_{-1} a) \right\} e^{ikz \sec \alpha (1 + 1/k \sec \alpha)} \right]$$

$$E_y(0, z) =$$

$$\frac{-i I_0 \sec \alpha (\mu/\epsilon)^{\frac{1}{2}}}{4\pi} \left[ \left\{ p_1 K_1(p_1 a) - k \cos \alpha K_0(p_1 a) \right\} e^{ikz \sec \alpha (1 - 1/k \sec \alpha)} \right. \\ \left. - \left\{ p_{-1} K_1(p_{-1} a) + k \cos \alpha K_0(p_{-1} a) \right\} e^{ikz \sec \alpha (1 + 1/k \sec \alpha)} \right]$$

where  $K_1$  and  $K_0$  are Bessel functions and  $p_n$  is given by:

$$p_n^2 = \left[ (n/a \tan \alpha) - k \sec \alpha \right]^2 - k^2 \quad \text{with } k = \omega \sqrt{\mu \epsilon}$$

$I$  = total current carried by the wire

$$i^2 = -1$$

$\alpha$  = pitch angle of helix

$\epsilon$  = dielectric constant

$\mu$  = permeability

For ease in manipulation the following substitutions are made:

Let

$$A = \frac{-I_0 \sec \alpha (\mu/\epsilon)^{\frac{1}{2}}}{4\pi}$$

$$B = p_1 K_1(p_1 a) - k \cos \alpha K_0(p_1 a)$$

1. The first part of the paper is devoted to a discussion of the general principles of the theory of the structure of the liquid phase of a crystal.

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$$C = p_{-1} K_1(p_{-1} a) / k \cos \alpha K_0(p_{-1} a)$$

$$D = ikz \sec \alpha$$

$$E = ikz \sec \alpha / k a \sec \alpha$$

Then the equations may be expressed as:

$$E_x = A(Be^{D-E} / Ce^{D/E}) = Ae^D (Be^{-E} / Ce^{E/E})$$

$$E_y = iA(Be^{D-E} - Ce^{D/E}) = iAe^D (Be^{-E} - Ce^{E/E})$$

Thus

$$E_x / E_y = Ae^D Be^{-E} (1 / i) / Ce^{E/E} (1-i)$$

which shows that the field can be expressed as two circularly polarized waves of opposite polarization, unequal in amplitude, and traveling in opposite directions.













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